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INTERFEROMETRIC MEASURING DEVICE

The present invention relates to an interferometric measuring device for measuring the shape of the surface of an object, using a radiation source emitting short-coherent radiation, a beam splitter for forming an object beam directed to the object via an object light path and for forming a reference beam directed to a reflecting reference plane via a reference light path, and having an image converter which picks up the radiation reflected from the surface and the reference plane and brought to interference, and sends it to an analyzing device for determining a measuring result pertaining to the surface, the optical length of the object light path being altered relative to the optical length of the reference light path.

Background Information

An interferometric measuring device of this type is described in German Patent Application 41 08 944 A1 (where the scanning of an intermediate image given as an alternative in the present document is not mentioned). With this known interferometric measuring device based on the so-called measuring principle of white-light interferometry or short-coherence interferometry, a radiation source emits short-coherent radiation which is split by a beam splitter into an object beam which illuminates a measuring object and a reference beam which illuminates a reflective reference plane in the form of a reference mirror. To scan the object surface in the depth direction, the reference mirror is moved in the direction of the optical axis of the reference light path by a piezo control element. When the object light path corresponds to the reference light path, the maximum interference contrast

is obtained in the area of the coherence length and is detected by a photoelectric image converter and a downstream analyzing device and is analyzed on the basis of the known deflection position of the reference mirror to determine the contour of the object surface.

Additional such interferometric measuring devices and interferometric measuring methods based on white-light interferometry are described by P. de Groot, L. Deck, "Surface profiling by analysis of white-light interferograms in the spatial frequency domain" J. Mod. Opt., Vol. 42, No. 2, 389-401, 1995 and Th. Dresel, G. Häusler, H. Venzke, "Three-dimensional sensing of rough surfaces by coherence radar," Appl. Opt., Vol 31 no. 7, 919-925, 1992.

In German Patent Application 199 48 813 (not pre-published) such an interferometric measuring device based on white light interferometry is also shown, the lateral resolution being increased particularly for measurement in narrow cavities by creating an intermediate image in the objective light path. German Patent Application 100 15 878.1, likewise not published previously, proposes scanning of an intermediate image to increase the depth of focus, with a relatively high lateral resolution at the same time.

There are problems with the known interferometric measuring devices and measuring methods if the measurement task requires scanning of several separated surfaces which are several millimeters apart, for example, and/or are oriented at an inclination to one another.

The object of the present invention is to provide an interferometric measuring device of the type defined in the preamble with which at least two spatially separated surfaces may be measured with accurate and highly reproducible measurement results.

Summary of the Invention

This object is achieved by the features of Claims 1 and, alternatively, 3. According to these features, superposition optics having multifocal optics or free segment optics is provided from various imaging elements in the object light path; simultaneously, using the superposition optics, an image may be created of at least one further surface in addition to the surface, which are imaged directly, or via at least one intermediate image in the object light path, on the image converter; and the measurement of the surface and of the at least one further surface takes place accompanied by a relative change in the optical length of the object light path to the optical length of the reference light path (scan). Alternatively, in the object light path, imaging optics having a depth of focus of at least the optical path difference of the two surfaces is provided, which may be used to simultaneously produce an image, apart from that of the surface, of at least one further surface disposed in front of it or behind it and parallel to it, or of surfaces arranged at an angle or at right angles to one another via optical deflection elements, and this image is imaged via at least one intermediate image in the object light path on the image converter, and that the measurement of the surface and of the at least one further surface takes place accompanied by a relative change in/ the optical length of the object light path to the optical length of the reference light path.

Using these measures, exact measurement of the different surfaces is made possible, without renewed alignment of the object light path. For registering the reference maximum, the optical lengths of the reference light path and of the object light path merely have to be set one after the other in correspondence to the positions of the various surfaces. In this connection, the free-segment optics may be easily adapted, for example, even to surfaces placed at an angle to each another or surfaces lying opposite each other. Using the

multifocal optics, and also using imaging optics having a depth of focus of at least the optical path difference of the two surfaces, surfaces may be measured which are far removed from each other and oriented differently to each other, and also, for example, their parallelism or surface evenness, thickness and diameter.

Various favorable embodiments also include the fact that the object light path for generating a common intermediate image of the surface and of the intermediate image of the additional surface(s) is formed in a common intermediate image plane in the object light path, and that the common intermediate image is imaged on the image converter either directly or by way of at least one intermediate image. With at least one intermediate image, on the one hand, scanning an intermediate image is possible, and on the other hand, so is obtaining an increased lateral resolution.

A measurement having relatively great lateral resolution even in narrow cavities is easily conducted when it is provided that the object light path is formed as an endoscope.

To achieve accurate measurement results, it is also advantageous that an optical fiber is provided for illuminating the object with a planar wave, its output on the object end being situated in a telecentric imaging arrangement of the object light path, or that an illumination light path having additional lenses and deflector elements is formed.

The measurement is made possible or further facilitated by the fact that the reference light path has optics similar or identical to that of the object light path, making it possible to produce the interference or optimize the interference contrast or compensate for optical effects of the components in the object light path.

Various options for easily measuring various surfaces even in

hard-to-reach places are obtained due to the fact that an optical system that is rigid relative to the object is situated in the object light path, and that the rigid optical system is followed by an optical system that is movable in the direction of its optical axis.

A favorable design for the construction and handling is to have the rigid optics be a part of the superposition optics.

To achieve a robust measurement with respect to relative lateral movement of the object, it is advantageous for the rigid optics to produce images toward infinity.

Furthermore, in accordance with one advantageous embodiment of the present invention, the rigid optics is designed as superposition optics, which is used to produce at least one intermediate image that is rigid relative to the object, and an objective optical system designed as movable optics following behind the rigid intermediate image in the path of the beam is movable in the direction of its optical axis for scanning the intermediate image which is normally aligned to this axis in the depth direction and is designed for imaging the same directly on the image converter or by way of one or more intermediate images. Due to the creation of the rigid intermediate image of the object surface situated, for example, in the object light path using the superposition optics in the object light path, the object surface to be measured is detectable with a relatively high lateral resolution, even in narrow channels or boreholes, and is evaluable with regard to the depth structure by using the image converter or the downstream analyzing device. The rigid intermediate image is scannable with relatively simple measures because only few optical components of the object light path need be moved for the depth scanning, the scanned depth of the rigid intermediate image, in each case, always remaining within the range of the depth of focus of the movable objective optics since due to the depth scanning

(depth scan), the object plane of the moving objective optics is likewise moved through the rigid intermediate image, and in this way, for example, the interference peaks are analyzed in the area of the greatest depth of focus.

The imaging quality and the accuracy of the analysis are favored by the fact that the intermediate image has the same linear magnification for all object points imaged in the intermediate image. In this connection, the design can be such that the rigid optics are formed as a 4f arrangement.

With respect to the design of the rigid optics and the movable optics, we refer additionally to German Patent Application No. 101 15 524 by the same applicant.

Brief Description of the Drawings

The present invention is elucidated in the following on the basis of exemplary embodiments, reference being made to the drawings.

The figures show:

Fig. 1 a schematic diagram of an interferometric measuring device according to the principle of white-light interferometry (short-coherence interferometry) having a free-segment optical system, the free-segment optical system being illustrated in two positions rotated by 90^0 relative to each other,

Fig. 2 a further exemplary embodiment of the interferometric measuring device, a superposition optics having separated refracting elements in the object light

path,

Figure 3 another exemplary embodiment of an interferometric measuring device, bifocal optics being situated in the object light path,

Figure 4 another exemplary embodiment of an interferometric measuring device in which the radiation in the reference light path and in the object light path is guided by optical fibers, and

Figure 5 another exemplary embodiment of the interferometric measuring device in which the radiation is guided in the object light path via an illumination light path having lenses and deflector elements.

Description of the Exemplary Embodiments

As shown in Figure 1, an interferometric measuring device based on the principle of white-light interferometry (short-coherence interferometry) has an object light path OW, a reference light path RW, an image converter BW having a downstream analyzing device, as is known per se and described in greater detail in the publications cited in the introduction as well as the literature named therein. This makes use of the fact that interference occurs only in the area of the coherence length, thus permitting simple coordination of the optical path lengths of reference light path RW and object light path OW as well as, for example, detection of the interference peak. In this connection, radiation emitted by a short-coherent light source KL has a coherence length on an order of magnitude such as 10 μm. The radiation of short-coherent light source KL is split by a beam splitter ST into a reference beam, which is guided via reference light path RW, and an object beam, which is guided via object light path OW. A fourth and fifth lens L4, L5 are situated in the light path to image converter BW for imaging.

The measurement is made possible or further facilitated by the fact that the reference light path has optics similar or identical to that of the object light path, making it possible to produce the interferences or optimize the interference contrast or compensate for optical effects of the components in the object light path.

As a further special feature, a superposition optics in the form of a free-segment optics FO is arranged in object light path OW, and it is represented in the diagrams on the right-hand side in cross section (upper diagram), in a 0^0 view (middle diagram) and in a 90^0 view (lower diagram) in a state in which a valve boring BO is carried up to the vicinity of a valve seat VS. As an additional special feature, superposition optics in the form of a free-segment optics FO is situated in object light path OW and shown in cross section (top diagram) in a 0^0 view in the illustration shown at the right (middle diagram) and in a 90^0 view (bottom diagram) in a state in which it is guided into a valve bore BO in proximity to a valve seat VS. Several separate surfaces A, B of bore BO or of valve seat VS can be detected at the same time with free-segment optics FO and imaged in a common intermediate image ZW in an intermediate image plane in the object light path, which is perpendicular to a main optical axis of object light path OW. Free-segment optics FO has several light deflecting surfaces and imaging refracting elements and is adapted to the respective measurement requirements. In particular, surfaces A, B situated at different distances from common intermediate image ZW and also situated at an inclination to each other or opposite to each other may be detected and imaged in the common intermediate image ZW.

Detecting the interference maxima corresponding to the two surfaces A, B takes place by changing reference light path RW corresponding to a scanning direction r. The moved unit is shown by dotted lines.

Superposition optics situated in object light path OW has two collimated lenses, namely a first lens L1 and a second lens L2 having different focal lengths, which may have prism-shaped elements situated in front of them. The object light path is also designed for producing a telecentric image. Surfaces A, B situated parallel to one another and different distances apart, e.g., a few µm to more than 1 cm, and perpendicular to the main optical axis of object light path OW are imaged in an intermediate image plane in the object light path with two lenses L1 and L2 in common intermediate image ZW composed of intermediate image ZA of surface A and intermediate image ZB of surface B. The focal lengths of first and second lenses L1, L2 are given as F_A, F_B. In addition, a third lens L3 for imaging is situated in the beam path of object light path OW. To record the interference peak, mirror SP is moved in the scanning direction r.

Figure 3 illustrates an embodiment of the interferometric measuring device in which, as opposed to Figure 2, instead of two lenses L1, L2, a bifocal optics LB is situated, its properties corresponding approximately to those of the two lenses L1, L2.

In the exemplary embodiment illustrated in Figure 4, additional lenses L6, L7 are introduced into the beam path of the object light path of bifocal optics LB on the object side. In addition, an optical fiber LL via which short-coherent radiation is conveyed from radiation source KL to illuminate surfaces A, B with a planar wave front via additional lens L7 is also situated in object light path OW. Essentially, corresponding lenses are also situated in reference light path RW for compensation and the radiation is also passed in the object light path via an optical fiber.

In Figure 5, in comparison with Figure 4, optical fiber LL in object light path OW is replaced by an imaging light path LW having discrete additional lenses LZ1, LZ2 and deflector

elements AE1, AE2 to illuminate surfaces A, B with a planar wave. Additional lenses L6, L7 are not provided here.

Surfaces A, B that are spatially separated from one another may be measured at the same time using the interferometric measuring devices described above and special optics in the form of the superposition optics mentioned above. The distance apart, and/or thickness, parallelism and diameter of spatially separated surfaces A, B can be measured in this way. The spatially separated surfaces may be imaged on image converter BW directly or via a common intermediate image ZW in the object light path.

Common intermediate image ZW may be imaged, directly or by way of one or more intermediate images in the object light path, on image converter BW, e.g., a CCD camera.

The design of the interferometric measuring device is implemented in the form of a Michelson interferometer, for example. Short-coherent radiation source KL may be, for example, a superluminescence diode or an LED. With illumination through the superposition optics, spatially separated surfaces A, B of the object are illuminated, in which case it is advantageous to illuminate separate surfaces A, B with almost planar waves.

The superposition optics in the form of free-segment optics FO may be composed, for example, of various individual lens systems which image different surfaces along different optical axes and with different optical path lengths in the common intermediate image plane. Free-segment optics FO may be implemented in the form of optical elements such as spherical lenses, aspherical lenses, rod lenses or Grin lenses or diffractive optical elements or prisms or mirrors, which may also be combined with one another.

Instead of the design of superposition optics as a bifocal

optics LB, multifocal optics may also be used if more surfaces are to be measured. The multifocal optics may be combined with another lens to form a telecentric arrangement, for example.

For compensation of the optical path lengths and the dispersion in both arms of the interferometer, namely reference light path RW and object light path OW, the fiber lengths and geometries of the optical fibers used should be as identical as possible.

The superposition optics may also be implemented approximately by optics having a great depth of focus or with an expanded depth of focus such as Axicon.

In the case of multifocal optics or bifocal optics as the superposition optics, optics having only one focal plane may also be used for compensation in reference light path RW, as shown in Figure 3.

An image of surfaces A, B to be observed superimposed by the reference wave is produced on image converter BW. For data analysis, a change is produced in the path difference between the optical path lengths in the object light path and the reference light path (deep scan), the change being caused by scanning movement r, for example. According to the related art, various procedures may be provided to change the difference in path, e.g., movement of the reference mirror, movement of the object in the depth direction, movement of the objective in the depth direction, movement of the entire sensor relative to the object or intermediate image scanning according to German Patent Application 100 15 878 or a change in the optical path length due to acousto-optical modulators.

A high interference contrast occurs in the image of the object when the path difference in both interferometer arms is less than the coherence length. For obtaining the 3-D height profile, various methods have become established. They are

based on the fact that, during depth scanning, the path difference is detected, for each image point (pixel), at which the highest fringe contrast occurs.